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AN INVESTIGATION OF THE COEXISTENCE OF 802.11g WLAN AND HIGH DATA RATE BLUETOOTH ENABLED CONSUMER ELECTRONIC DEVICES IN INDOOR HOME AND OFFICE ENVIRONMENTS

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ABSTRACT

The anticipated proliferation of various wireless local area network (WLAN) enabled devices in the near future is likely to result in increased mutual interference in the 2.45GHz Industrial, Scientific and Medical (ISM) band. This work investigates the impact of standard Bluetooth and High Data Rate (HDR) Bluetooth interference on 802.11g enabled consumer electronic devices and vice versa. Technical design issues for HDR Bluetooth and 802.11g systems implemented in software are presented. Packet Error Rate (PER) vs. Signal to Noise Ratio (SNR) plots are presented. The improvement in performance attained in 802.11g systems by using erasures in the corrupted subcarriers is briefly discussed as a conclusion to the paper.

INTRODUCTION

There is growing concern for mutual interference between users of different consumer electronic devices such as PDAs, mobile telephones, and cordless TV and VCR following the avalanche of WLAN systems appearing in the market. The once under-utilised ISM band is now becoming cluttered with 802.11 compliant WLAN systems such as 802.11b [1] and 802.11g [2], Bluetooth [3] devices, Home RF and a plethora of other unlicensed systems.

In order for interference to occur between consumer electronic devices operating in close proximity to one another, an overlap in both frequency and time is required. When these collisions occur, the data packet being transmitted may become corrupted leading to a retransmission. Consequently, this leads to significant performance degradation in terms of data throughput for time-bounded and non time-bounded applications.

This paper presents novel research results on the impact of HDR Bluetooth enabled consumer electronic devices on 802.11g enabled devices. The level of interference is governed by factors such as the transmit power levels, proximity of the devices relative to one another and also the duration of transmission (the packet size).

IEEE 802.11g WLAN SYSTEM

The newly developed 802.11g physical layer standard specifies a link adaptive Coded Orthogonal Frequency Division Multiplexing (COFDM) scheme (as for 802.11a) for operation in the 2.4GHz ISM band. OFDM modulation is implemented by means of an inverse FFT. 48 data symbols and 4 pilots are transmitted in parallel in each OFDM symbol. Various combinations of coding rate (for an FEC convolutional code) and modulation schemes are specified in a similar manner to 802.11a to facilitate different 'modes' of transmission. Backwards compatibility with the CCK DS-CDMA modulation of 802.11b is also mandated. The analysis presented in this paper concentrates on the eight modes of 802.11g which are equivalent to those of 802.11a. These eight modes are summarized in Table I. 802.11g supports. Table II summarises the duration of transmission for packets of various payload sizes.

TABLE I. IEEE 802.11a/g TRANSMISSION MODES

Mode	Modulation	Coding Rate	Nominal Data Rate, $R_{Nominal}$
1	BPSK	1/2	6 Mbits/s
2	BPSK	3/4	9 Mbits/s
3	QPSK	1/2	12 Mbits/s
4	QPSK	3/4	18 Mbits/s
5	16QAM	1/2	24 Mbits/s
6	16QAM	3/4	36 Mbits/s
7	64QAM	2/3	48 Mbits/s
8	64QAM	3/4	54 Mbits/s

TABLE II. PSDU DURATION FOR DIFFERENT MODES AND PAYLOADS

Mode	Payload			
	256 bytes	500 bytes	1000 bytes	2000 bytes
1	348 μs	672 μs	1340 μs	2672 μs
2	232 μs	448 μs	892 μs	1784 μs
3	176 μs	336 μs	672 μs	1336 μs
4	116 μs	224 μs	448 μs	892 μs
5	88 μs	168 μs	336 μs	668 μs
6	60 μs	112 μs	224 μs	448 μs
7	44 μs	84 μs	168 μs	336 μs
8	40 μs	76 μs	152 μs	300 μs

BLUETOOTH AND HDR BLUETOOTH

Bluetooth is a point-to-point radio standard intended to replace wires and cables in electronic devices. Bluetooth technology operates in the unlicensed 2.45 GHz ISM band and utilises frequency hopping with terminals cycling through 79 1MHz hop channels at 1600 hops/s. A HDR extension to the currently available 1Mb/s Bluetooth link has been proposed in [4]. From the study, the use of M-PSK and the QAM family of modulation schemes with coherent detection was recommended in order to be able to increase the data throughput (up to 6Mb/s) to allow a greater range of consumer electronic devices. Further investigations have addressed self-interference issues between HDR Bluetooth devices. Spatial-temporal techniques were proposed as solutions towards achieving usable data rates in HDR Bluetooth enabled consumer electronic devices [5].

MODELLING HDR BLUETOOTH AND 802.11g INTERFERERS

In HDR Bluetooth, each time slot has a duration of 625μs and packets may occupy 1, 3 or 5 time slots. The system uses a single hop frequency for the entire span of a packet. A significant proportion of a slot time is reserved at the end of each packet to allow for transient settling time. 1, 3 and 5 time slot packets utilise the channel for 366μs, 1666μs and 2966μs respectively. Since the bandwidth for HDR Bluetooth is maintained at 1MHz and a similar hop pattern is employed, in this paper it is assumed that the impact of HDR Bluetooth on 802.11g is similar to that of standard Bluetooth on 802.11g.

From Table II, it can be seen that the ratio of the 802.11g to Bluetooth packet duration will have implications on the probability of collision between the two systems. In the extreme case, collision is almost certain if the 802.11g system operates using 2000 byte packets in Mode 1 whilst the Bluetooth system uses single time slot packets. The Bluetooth signal acts as a narrowband interferer with a probability of overlap of 16.25/79≈20% (since the occupied bandwidth of 802.11g is 16.25 MHz, 52 (out of 64) usable subcarriers). Figure 1 illustrates Bluetooth interfernce on WLANs.

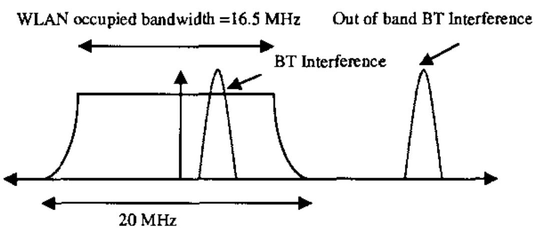

Figure 1: Bluetooth interfernce on 802.11g WLANs

The frequency hopping statistics in Bluetooth show that the frequency hops alternately between odd and even frequency bands across the 79-hop system. This is to avoid co-channel interference in Bluetooth since the RF bandwidth is approximately 1.5MHz (taking into account an RF offset of ±150kHz, a local oscillator frequency drift of ±80kHz and filter roll-off). The simulations carried out therefore apply the frequency hop pattern to ensure that the model approximates a true realisation of the interference that is being modelled.

RESULTS

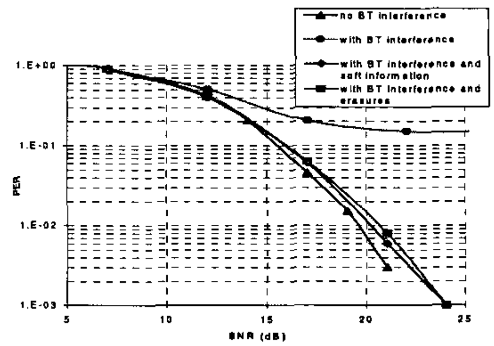

Figure 2: PER Performance of 802.11g with single time-slot standard Bluetooth interference for mode5 with a PSDU size of 500 bytes.

Figure 2 shows the PER performance of 802.11g for mode 5, PSDU size of 500 bytes, with -11dB C/I. In Figure 2, three cases have been simulated. In the first case, no erasures were applied. Erasures were applied to corrupted subcarriers. This meant that the erased data was completely removed from the Viterbi convolutional decoding trellis. The error floor is due to the fact that the data on the specific subcarriers are corrupted and the channel state information for these subcarriers is wrong since the preamble which is responsible for the channel estimation is also corrupted. For the second case, erasures were used for the three sub-carriers at the centre of the Bluetooth interference in addition to soft values (based on the C/I) for the other affected subcarriers. For the third case, 5 erasures were used. It can be seen that the performance is similar for the second and third cases for this interference value. When the receiver, and more particularly the soft decision Viterbi decoder have knowledge of the position of the corrupted subcarriers it can compensate for the few corrupted subcarriers. As can be seen from Figure 2, performance is very close to a system without Bluetooth interference. Due to lack of space in this paper, results for 802.11g interferers on HDR Bluetooth will be presented in the transaction paper. Typical scenarios for indoor home and office environments will be constructed and data throughput and coverage performance will be discussed for time-bounded and non time-bounded consumer electronic devices.

REFERENCES

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[2] IEEE Std 802.11g/D1.1-2001, Part11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Further Higher-Speed Physical Layer Extension in the 2.4 GHz Band.

[3] The Bluetooth Standard Version 1.0b (http://www.bluetooth.com)

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